


Vitamin A supplementation among 9–59 months old children in India: geospatial perspectives and implications for targetted coverage

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To cite: Bora K. Vitamin A supplementation among 9–59 months old children in India: geospatial perspectives and implications for targetted coverage. *BMJ Global Health* 2022;**7**:e007972. doi:10.1136/bmjgh-2021-007972

Handling editor Seye Abimbola

► Additional supplemental material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/bmjgh-2021-007972>).

Received 11 November 2021
Accepted 2 May 2022



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ABSTRACT

Introduction Vitamin A supplementation (VAS) is yet to reach all Indian children aged 9–59 months, despite guidelines for universal coverage. This study mapped geospatial patterns underlying VAS coverage across two policy-relevant administrative unit levels (states and districts) in India. The relationship between spatial distribution of VAS coverage and vitamin A deficiency (VAD) prevalence was also investigated.

Methods The study draws on nationally representative cross-sectional data collected during National Family and Health Survey 4 (NFHS-4) and Comprehensive National Nutritional Survey (CNNS). VAS coverage was estimated using information obtained during NFHS-4 from mothers about whether their children (n=204 645) had received VAS within 6 months of the survey. VAD prevalence estimates were based on serum retinol measurements during CNNS in under-five children (n=9563). State-level and district-level choropleth maps of VAS coverage were constructed. Spatial patterns were probed using Moran's statistics, scatter plots and local indicators of spatial association (LISA). Relationship between VAS coverage (as an explanatory variable) and VAD prevalence was explored using spatial autoregressive models.

Results VAS coverage in India (overall 60.5%) ranged from 29.5% (Nagaland) to 89.5% (Goa) across the various states/union territories. Among districts, it ranged from 12.8% (Longleng district, Nagaland) to 94.5% (Kolar district, Karnataka). The coverage exhibited positive spatial autocorrelation, more prominently at the district-level (univariate Moran's $I=0.638$, $z\text{-value}=25.614$, pseudo $p\text{ value}=0.001$). LISA maps identified spatial clusters of high coverage and low coverage districts. No significant spatial association was observed between VAS coverage and VAD prevalence in the states during spatial error ($R^2=0.07$, $\lambda=0.30$, $p\text{ value}=0.14$) and spatial lag ($R^2=0.05$, $\rho=0.25$, $p\text{ value}=0.23$) regression.

Conclusion Two out of every five eligible Indian children were not supplemented with vitamin A. The coverage was geographically heterogeneous with discernible spatial patterns. Their consequences on vitamin A status and associated health effects in the community deserve close monitoring.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ High doses of vitamin A supplementation (VAS) are recommended prophylactically in all Indian children aged 9–59 months to curb vitamin A deficiency (VAD), which is recognised as an important but controllable public health problem in the country.

WHAT THIS STUDY ADDS

⇒ Using nationally representative data, the current study mapped the VAS coverage across 640 districts in India encompassing all the 29 states and 7 union territories.
⇒ Outreach of VAS in India was highly variable with considerable coverage gaps, that conformed to spatially significant and distinct patterns.
⇒ The spatial distribution of VAD prevalence in the states was not associated with the corresponding rates of VAS coverage.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

⇒ The impact of geospatial heterogeneity underlying VAS coverage on vitamin A status and associated health effects in India deserve careful monitoring.
⇒ Microplanning and evidence-based approaches are necessary to address the existing programmatic gaps and to ensure that appropriate vitamin A interventions are delivered to the people in need.

INTRODUCTION

Vitamin A refers to a group of fat-soluble vitamins belonging to the retinoid family and their derivatives (viz, retinol, retinal, retinoic acid, retinyl esters).^{1 2} It mediates important cellular processes in the human body (eg, phototransduction, cell proliferation, differentiation, signalling) that are critical for vision, growth and development, wound healing, reproduction and immunity among other biological functions.^{1–5} Due to the absence of de novo synthesis in humans, vitamin A is an essential micronutrient whose physiological requirement is met by its dietary intake directly or that of its

precursor (β -carotene).¹⁶ Thus, poor nutrition and inadequate reserves may lead to vitamin A deficiency (VAD), a condition often exacerbated by infective episodes (eg, measles, diarrhoea) and common in under-five children from developing countries.¹⁷ Globally, an estimated 190 million (or one in three) children below the age of 5 years are afflicted by VAD.^{17,8} Though frequently subclinical, VAD often leads to clinically significant manifestations in children (such as xerophthalmia, keratomalacia, blindness, impaired growth and development, vulnerability to infections, poor wound healing),¹⁷⁻¹⁰ with far-reaching consequences in terms of both morbidity and mortality.⁸⁻¹²

In view of the above, the WHO endorses the practice of periodically providing prophylactic vitamin A supplementation (VAS) in high doses to under-five children in settings where VAD is a public health problem.¹³ Childhood VAD has been long recognised as an important but controllable public health problem in India.¹⁴⁻¹⁸ In fact, recent estimates based on the Comprehensive National Nutrition Survey (CNNS), conducted between March 2016 and October 2018, indicated that the prevalence of VAD is still considerable in various parts of the country.¹⁹⁻²¹ Since 2006, the Government of India recommends periodic administration of high-dose vitamin A oral supplements universally to all children below 5 years of age (total nine such doses, with minimum 6 months gap between two consecutive doses) under a policy decision to prevent VAD.²² This universal VAS prophylaxis programme constitutes the chief public health intervention against VAD in the country. Accordingly, the first dose (100 000 IU) is recommended on contact with an infant at the age of 9 months during the time of providing measles vaccine (under Universal Immunisation Programme), and thereafter the second to ninth doses (200 000 IU each) are recommended biannually till the age of 5 years.^{22,23} Other efforts to combat VAD in India include fortification of cooking oil and milk with retinyl esters, but the regulatory framework was drafted very recently.²⁴

In spite of operational guidelines for universal prophylaxis, VAS is yet to reach all eligible children in India.^{25,26} However, the geospatial patterns underlying the heterogeneity and gaps in VAS coverage are hitherto unexplored. Exploratory spatial data analysis techniques offer a robust and objective toolset for assessing the outreach and impact of public health policies and healthcare delivery (including child health services).^{27,28} They aid in identifying and targeting 'high priority' locations where the observations of interest are unusually concentrated. The present study attempted to map the subnational coverage of VAS among 9–59 months old Indian children at a geographical scale across two policy-relevant administrative unit levels (ie, the state-level and district-level), and probed if the observed coverage conformed to spatially significant patterns. It also investigated if VAD prevalence across the country was related to the coverage of VAS.

METHODS

Study setting and data sources for VAS coverage

The present study relied on data collected during the fourth round of the National Family and Health Survey 4 (NFHS-4), conducted under the Demographic and Health Surveys (DHS) programme in India between January 2015 and December 2016. Multiple variables (viz, health, socioeconomic, demographic and behavioural) were surveyed in this nationally representative cross-sectional study at a population level encompassing all the 640 districts located in 29 states and 7 union territories (UTs).²⁹ The participants included 699 686 women and 112 122 men, enrolled from 601 509 households all over the country using a stratified two-stage sampling process (with the 2011 census of India serving as the sampling frame).

The methodological details and data collection tools used in NFHS-4 have been described previously.²⁹ Briefly, four questionnaires (namely household questionnaire, woman's questionnaire, man's questionnaire and biomarker questionnaire) were used in the survey. Information about health and nutrition in children (including vitamin A supplementation) were collected from mothers with the help of the woman's questionnaire. The question 'Within the last 6 months, was (NAME OF THE CHILD) given a vitamin A dose (like this/any of these)?' in that questionnaire was relevant for the present study. Common vitamin A preparations (eg, vitamin A syrups) were shown as visual aids to the mothers. A 'YES' response to the question was recorded if a child had received the last vitamin A dose within the past 6 months period before the survey (based on documentation in vaccination card or mother's recall). The NFHS-4 collected VAS-related information pertaining to 204 645 children (aged 9–59 months) in this manner, which constituted the data source for the present study.

Assessment of VAS coverage in children aged 9–59 months

The estimated proportion of children aged 9–59 months who received VAS within the last 6 months was retrieved at the state-level (covering 29 states and 7 UTs) and the district-level (covering 640 districts). The state-wise and district-wise coverage values of VAS were extracted from the respective state-level and district-level NFHS-4 reports,^{30,31} based on final data. These values were used to construct choropleth maps (applying both categorical and continuous scales) for illustrating the VAS coverage patterns by states and districts.

The variability in VAS coverage was quantified with the help of coefficient of variation (CV), calculated among the 36 states/UTs (interstate CV) and the 640 districts (interdistrict CV). The coverage variability among districts within a state was also computed (intrastate CV). The spread of the VAS coverage data were depicted graphically using boxplots.

Evaluation of spatial patterns in VAS coverage across India

Spatial weights generated through queen's contiguity criterion (of first-order) were applied to explore the

spatial patterns underlying VAS coverage across India. The analysis included both global and local approaches. The univariate global Moran's I statistic (a cross product statistic between the VAS coverage value and the spatial lag) was used in conjunction with Moran scatter plot to evaluate if the coverage of VAS exhibited spatial patterns as opposed to the null hypothesis of spatial dispersion (which states that the VAS coverage is random without any spatial relationship). This was explored separately at the state-level and district-level. The Moran's I value may range from -1 to $+1$, with a positive value indicating positive spatial autocorrelation (ie, spatial clustering, or the presence of similar values at neighbouring locations) and a negative value indicating negative spatial autocorrelation (ie, spatial outliers, or the presence of dissimilar values at neighbouring locations). The significance of the Moran's I value was checked using a permutation approach (that involved 999 computationally created permutations to generate a reference distribution of the statistic for significance testing), yielding a z-value and a corresponding pseudo p value. While a pseudo p value >0.05 provides no evidence of a spatial pattern, a value <0.05 rejects the null in favour of the alternative hypothesis suggesting an underlying spatial pattern (ie, either spatial clustering or spatial outlier, depending on the Moran's I value).^{32 33}

The global Moran's statistic offers a summary overview of the spatial patterns, but without providing information about location of the spatially significant areas. Therefore, locational information about the spatial patterns and their extent was investigated at the district level using the univariate local indicator of spatial association (LISA) method, which provided a local Moran's I statistic for each district (illustrated through LISA cluster map) with significance testing (illustrated through LISA significance map). The local Moran's I is a location-specific statistic that depends on neighbouring relations, with the neighbourhood structure being expressed through a spatial weights matrix. Essentially, the LISA approach establishes a proportional relationship between the sum of the local statistics and the corresponding global statistic. The LISA cluster map displayed four possible types of spatially significant patterns: 'high-high' clusters or hot-spots (consisted of districts with above-average VAS coverage surrounded by neighbours with above-average VAS coverage; shaded in dark red colour), 'low-low' clusters or cold-spots (consisted of districts with below-average VAS coverage surrounded by neighbours with below-average VAS coverage; shaded in dark blue colour), 'high-low' outliers (consisted of districts with above-average VAS coverage surrounded by neighbours with below-average VAS coverage; shown in light red shade) and 'low-high' outliers (consisted of districts with below-average VAS coverage surrounded by neighbours with above average VAS coverage; shown in light blue shade). In other words, the clusters (ie, 'high-high' and 'low-low' areas) represented contiguous districts that had more similar VAS coverage values to their neighbours

than would be expected under spatial randomness (ie, positive spatial autocorrelation). By contrast, the outliers (ie, 'high-low' and 'low-high' areas) were districts with VAS coverage values that were more dissimilar to their neighbours than would be expected under spatial randomness (ie, negative spatial autocorrelation).^{32 33}

The significance was assessed by generating reference distributions for all the local statistics (one for each district) with the help of 999 computationally created permutations, thereby producing a pseudo p value for every district. The LISA significance map highlighted the spatially significant locations at different pseudo p value cut-offs (using different shades of green) starting with 0.05. The non-significant locations (with spatially dispersed VAS coverage) were shown as unshaded locations in both LISA cluster and significance maps.

Evaluation of the spatial relationship between VAS coverage and VAD prevalence

Prevalence of VAD (defined as serum retinol <20 $\mu\text{g}/\text{dL}$, corrected for inflammation) among under-five children was recently estimated for 29 states and 1 UT in India (online supplemental material 1).¹⁹ These estimates were based on serum retinol measurements in 9563 children aged 1–5 years who were enrolled during CNNS across India through a multistage stratified probability-proportionate-to-size design.²¹ The midpoint of CNNS data collection period succeeded that of NFHS-4 by 18 months. Prophylactic VAS in children below 5 years is an ongoing activity in India that is repeated periodically every 6 months. Therefore, assuming that the VAS coverage estimated from the NFHS-4 data were comparable during CNNS, the influence of VAS coverage on the spatial distribution of VAD prevalence was investigated. Accordingly, bivariate global Moran's I was determined between VAD prevalence and spatially lagged VAS coverage values (without taking into account the potential correlation that may be inherently present between the two) to assess whether VAD prevalence in a given location and VAS coverage in neighbouring locations were spatially related. The statistical significance was tested using the 999 permutations procedure. Moreover, the spatial relationship between VAS coverage (as an explanatory or independent variable) and VAD prevalence (as a response or dependent variable) was evaluated using regression techniques. It involved preliminary analysis by ordinary least square (OLS) regression. Subsequently, spatial association between the two variables (if any) was tested by spatial autoregressive models, viz, spatial error model (SEM) and spatial lag model (SLM). The SEM model conceptualises the error terms across different spatial units to be correlated (ie, spatial autocorrelation is specified as a part of the error term), such that in the absence of spatial dependence this model is virtually similar to the OLS model. On the other hand, SLM conceptualises that the dependent variable in a location is affected by the independent variable in that location as well as neighbouring locations (ie, the model specification

incorporates spatially lagged dependent variable).^{32–34} The statistics λ (lambda) and ρ (rho) are, respectively, used to denote the spatial autoregressive parameter in SEM and SLM. Since VAD estimates were unavailable for districts, therefore these analyses (between VAS coverage and VAD prevalence) were limited up to the state-level aggregation only.

Statistical resources and considerations

Statistical analysis was conducted in SPSS V.17.0 (SPSS, Chicago, Illinois, USA) and Microsoft Excel (Microsoft Office Professional Plus 2019, Microsoft, Washington, USA) platforms. The spatial relationships were analysed and mapped in GeoDa V.1.18.0 software using state-level and district-level shapefiles for India. In general, a two-sided alpha at 0.05 was used as the threshold for statistical significance, unless otherwise specified. The statistical considerations at different stages of data analyses are described in the relevant subsections above.

Since the LISA analysis involves multiple comparisons among all the locations in the data set in turns, a true null hypothesis may be incorrectly rejected leading to false positives (ie, type 1 error) at the defined alpha threshold.^{32–35} However, there is no completely satisfactory solution for obtaining an equivocal alpha to the multiple comparisons problem which can ‘correctly’ reject all false positives while identifying the spatially significant clusters.^{32–35–37} In other words, false positives are inherent in LISA analysis and any choice of alpha is somewhat arbitrary. To minimise such false declarations of significance, it is therefore desirable to supplement the default LISA results (obtained using traditional alpha threshold at 0.05) with extensive and balanced sensitivity analysis, and to interpret the two sets of results in tandem. Accordingly, the sensitivity analysis was performed by setting the alpha cut-off at 0.01 and further by applying the false discovery rate (FDR) filter in GeoDa V.1.18.0. Since the FDR procedure requires a large number of permutations for adequate precision,^{32–35–36} the randomisation was performed through 99 999 permutations (ie, the highest feasible in the software).

Ethics

The protocol for NFHS-4 survey (including the survey questionnaires) was approved by Institutional Review Boards (IRB) of International Institute for Population Sciences and ICF International. The protocol was also reviewed by the US Centers for Disease Control and Prevention.²⁷ Additionally, permission to use and analyse these data for the current study was obtained from DHS in accordance with the IRB-approved procedures for public-use data sets under the DHS programme.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research that relied on secondary analysis of anonymised data available from publicly available sources.

RESULTS

Coverage of VAS among children aged 9–59 months in India

Overall, 123 836 (or 60.5%) of the 204 645 surveyed children aged 9–59 months had received supplements of vitamin A during NFHS-4 within the last 6 months of the survey. Among individual states and UTs (figure 1A), the highest VAS coverage was recorded in Goa (89.5%) followed by Sikkim (84.3%). The coverage was least in Nagaland (29.5%), followed by Manipur (32.1%), Uttarakhand (36.9%) and Uttar Pradesh (40.0%). At the district-level (figure 1B), the coverage ranged from 12.8% (in Longleng district of Nagaland) to 94.5% (in Kolar district of Karnataka). On a categorical scale, 71 out of the 640 districts (or 11.1% districts) in India achieved VAS coverage above 80%. This was in contrast to 13 districts at the other end of the spectrum where the VAS coverage was a meagre 20% or worse. It included four districts from Nagaland (Longleng, Mon, Phek and Zunheboto), three districts from Manipur (Ukhrul, Chandel and Senapati), three districts from Uttar Pradesh (Muzaffarnagar, Bareilly and Bahraich), two districts from Rajasthan (Dungarpur and Rajsamand) and one district from Arunachal Pradesh (East Kameng).

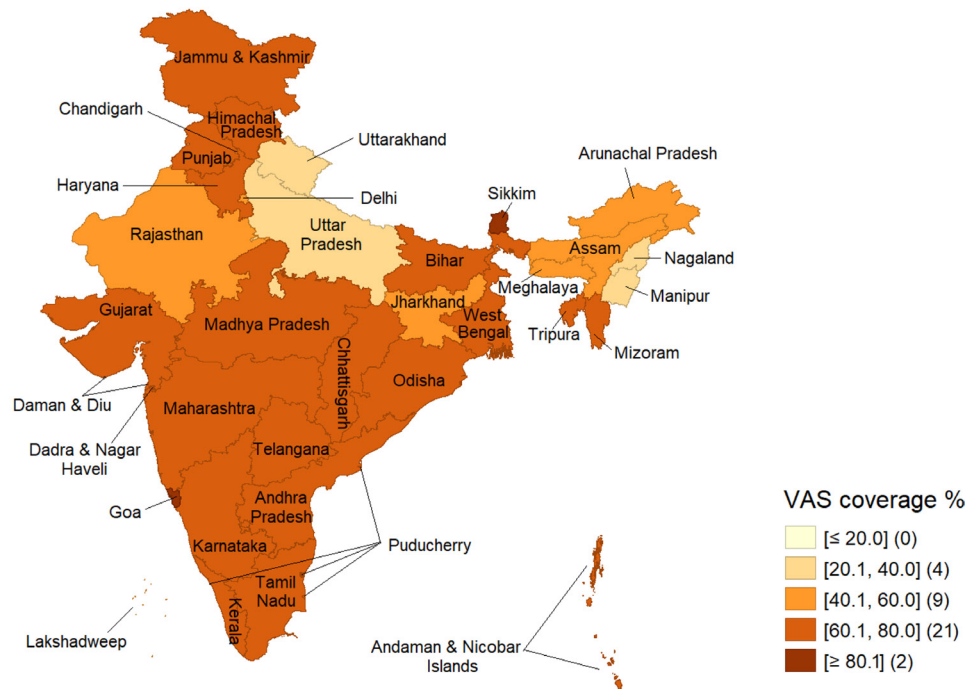
The choropleth maps on a continuous scale (online supplemental materials 2A,B) highlighted the presence of widespread disparities in VAS coverage across India. It was further corroborated by boxplots (online supplemental materials 3A) and CV calculations. The district-level variability in VAS coverage (interdistrict CV=28.9%) was comparatively more than that at the state-level (interstate CV=23.1%). As highlighted by the state-wise boxplots (online supplemental materials 3B) and intrastate CV values (online supplemental materials 4), there was considerable heterogeneity and variability in VAS coverage among different districts belonging to the same state/UT, as well. Nagaland exhibited the highest intrastate CV (47.7%) followed by Manipur (44.6%) and Arunachal Pradesh (32.7%). The intrastate CV was least in Puducherry (4.4%) followed by Sikkim (6.2%) and Goa (6.5%).

Spatial patterns underlying VAS coverage in children aged 9–59 months across India

The practice of VAS in 9–59 months old children across India demonstrated statistically significant spatial patterns. The observed coverage values were auto-correlated at the state-level (global Moran's $I=0.487$, $z\text{-value}=4.201$, pseudo $p\text{ value}=0.001$), signifying that the VAS coverage in the country tended to be spatially clustered (figure 2A). The clustering was more pronounced (figure 2B) when the spatial distribution was assessed at the district-level (global Moran's $I=0.638$, $z\text{-value}=25.614$, pseudo $p\text{ value}=0.001$).

The subsequent LISA analysis identified 256 districts (40.0% of the total districts) with spatially significant VAS coverage patterns at a threshold of $p<0.05$, out of which 55 districts were significant at $p<0.001$ (figure 3A,B). High rates of VAS coverage were clustered across 120 districts (hot-spots or ‘high–high’ districts), as opposed to 127 districts with a clustering of low VAS coverage

A State-level VAS coverage



B District-level VAS coverage

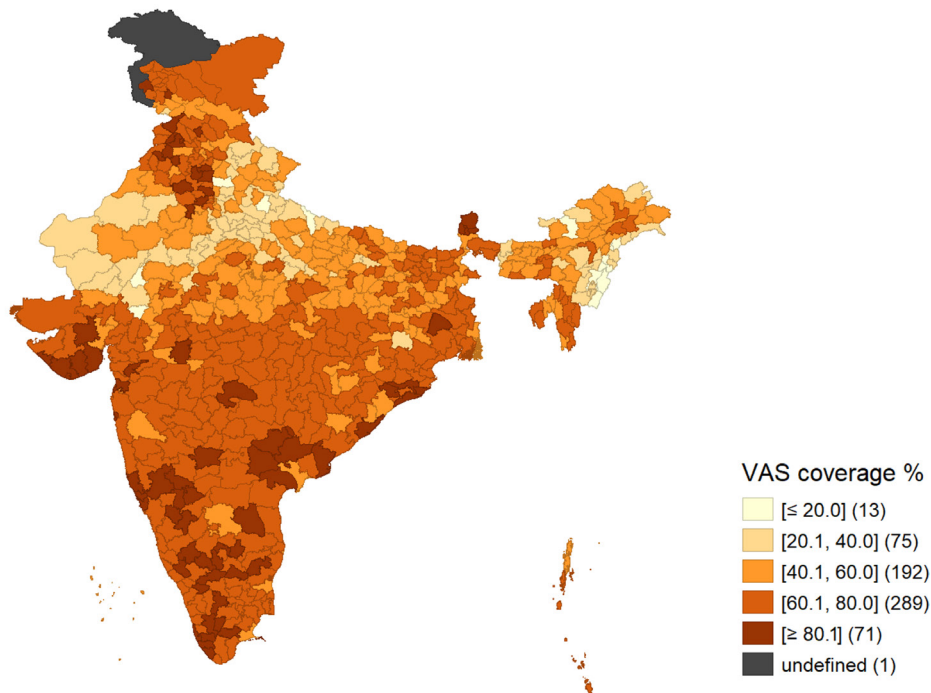


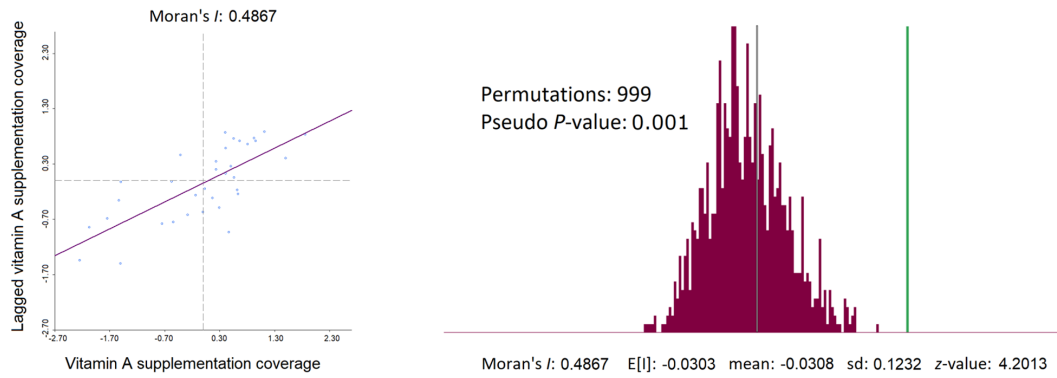
Figure 1 Choropleth maps showing coverage of vitamin A supplementation (VAS) among children aged 9–59 months in India, 2015–2016, across (A) states/union territories, and (B) districts. (Values within square brackets in the colour legends indicate the specified VAS coverage range, and values within round brackets indicate the number of states/union territories or districts belonging to that coverage range).

rates (cold-spots or ‘low–low’ districts). Nine districts (six ‘low–high’ and three ‘high–low’ districts) were significant spatial outliers. After sensitivity analysis (figure 3C,D), the clustering persisted in 61 districts (including 20 hot-spot districts and 41 cold-spot districts) and the outliers disappeared altogether.

Relationship between VAS coverage and VAD prevalence in India

Bivariate Moran scatter plot (figure 4) revealed that VAD prevalence and VAS coverage across the states of India were spatially not related (bivariate global Moran’s $I = -0.115$, $z\text{-value} = -1.131$, pseudo $p\text{ value} = 0.125$). The

A Global spatial autocorrelation (state-level)



B Global spatial autocorrelation (district-level)

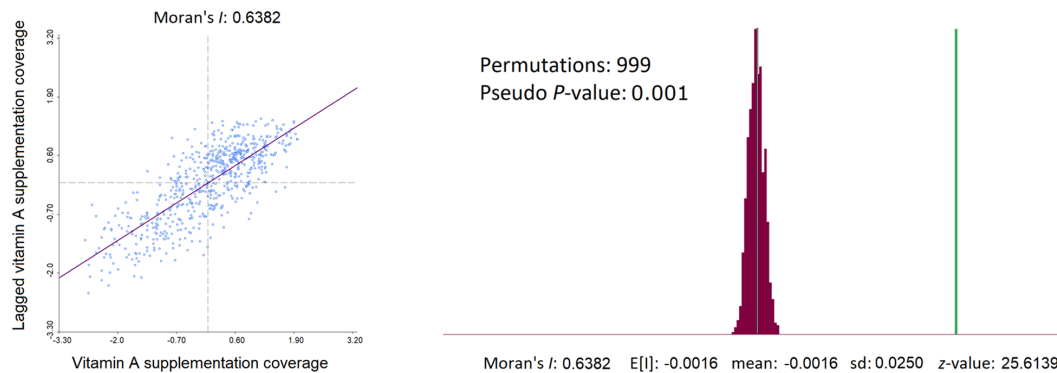


Figure 2 Global univariate Moran's I statistic with scatter plot showing spatial autocorrelation underlying the coverage of vitamin A supplementation at (A) state-level, and (B) district-level.

findings from spatial autoregressive modelling generated with the help of SEM ($R^2=0.07$, $\lambda=0.30$, p value=0.14) and SLM ($R^2=0.05$, $\rho=0.25$, p value=0.23) further substantiated the lack of spatial dependence between distribution of VAD prevalence in the states and their VAS coverage (table 1).

DISCUSSION

High-dose universal VAS is considered as a key strategy for addressing VAD and the associated health challenges in under-five children.^{13 38 39} The bulk of the childhood VAD cases in the world are concentrated in south Asia and sub-Saharan Africa.^{1 7 8 38 39} India, a south Asian country with a huge population and enormous diversity, has historically harboured a substantial share of the world's vitamin A-deficient children.^{1 7 8 15–17 38 39} Identified as one of the 'priority' countries for the universal supplementation of vitamin A in under-five children,^{16 38 39} effective implementation of India's VAS programme is therefore of much interest. The present study, based on NFHS-4 data, highlighted that only around 60% (or three in five) eligible Indian children were supplemented with vitamin A. This was low as compared with the contemporary coverage in most other south Asian countries, viz, Nepal (85%), Afghanistan (96%), Pakistan (96%), Sri Lanka (72%) and Maldives (76%).⁴⁰ In sub-Saharan Africa, the overall VAS coverage was 59.4%, ranging from 40.8%

(in Guinea) to 88.4% (in Senegal) among the different countries.⁴¹

Subnational variations were evident in the coverage of VAS across India. The variations were more prominent across the districts than across the states. Majority of the low VAS coverage locations were in Manipur, Nagaland, Arunachal Pradesh, Uttar Pradesh, Uttarakhand and Rajasthan. Whereas the states of Manipur, Nagaland and Arunachal Pradesh are situated in the northeastern region (NER) of India; the states of Uttar Pradesh, Uttarakhand and Rajasthan are located in northern India and belong to the Empowered Action Group (EAG) of states. Spread over remote and difficult terrain, the NER has logistical/infrastructural constraints and a significant tribal population. The access to quality healthcare services in NER states is limited as compared with the 'other' states of India.^{42–44} The EAG states have relatively poor sociodemographic indicators, high disease burden and inequitable health resources than the 'other' states of the country.^{42 43} Due to these factors, the EAG and the NER states often need special thrusts for development. On the contrary, the high VAS coverage areas were mostly spread across states such as Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Maharashtra, Goa, Gujarat, Sikkim, Punjab and Haryana. These states are relatively prosperous and generally rank high in health, demographic, socioeconomic and developmental indicators.^{42 44} Previous studies had observed differences in the outreach of VAS

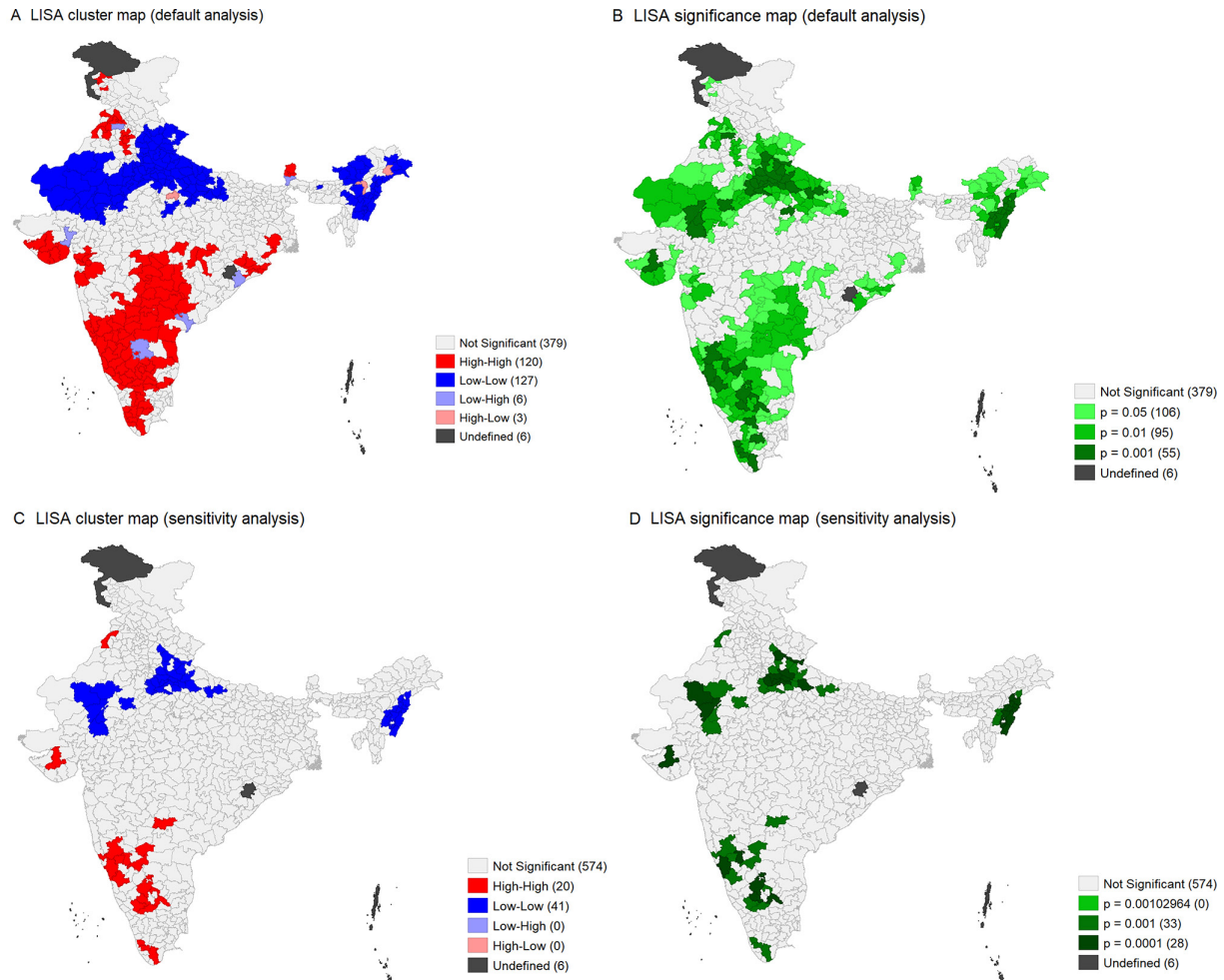


Figure 3 Spatial patterns with district-level locational information of vitamin A supplementation coverage across India, 2015–2016, unravelled by local indicator of spatial association (LISA) analysis, illustrated through (A) LISA cluster map (default analysis), (B) LISA significance map (default analysis), (C) LISA cluster map (sensitivity analysis) and (D) LISA significance map (sensitivity analysis). (Values within round brackets in the colour legends indicate the number of districts belonging to the specified category in the map).

by sociodemographic factors (eg, children from families belonging to lower socioeconomic status were less likely to be covered by VAS programmes than their well-to-do counterparts).^{26 45} As described above, the subnational variations in VAS coverage detected across India in the current study

largely affirms this tendency. However, there were some exceptions. For example, despite being EAG states with poor sociodemographic indicators, districts in Bihar and Odisha achieved appreciable VAS coverage levels. Their success stories,^{25 46} suggest that VAS programmes can reach

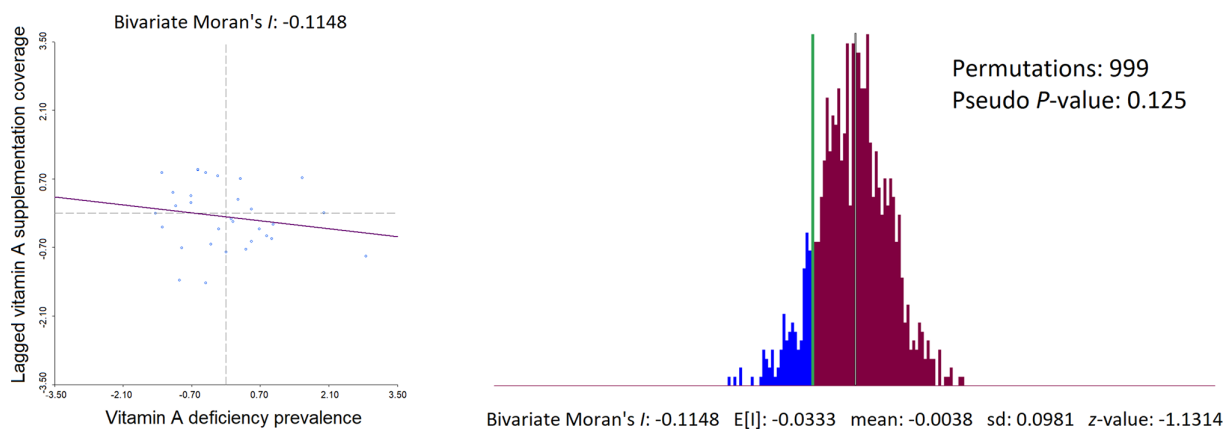


Figure 4 Relationship between prevalence of vitamin A deficiency and coverage of vitamin A supplementation across the states, examined by bivariate Moran's I statistic with scatter plot.

Table 1 Relationship between prevalence of vitamin A deficiency and coverage of vitamin A supplementation across the states, examined by different regression techniques

Model parameters	Ordinary least square model		Spatial error model		Spatial lag model	
	Estimate	P value	Estimate	P value	Estimate	P value
Regression co-efficient	0.01	0.92	0.08	0.52	0.04	0.72
Spatial autoregressive parameter, λ or ρ	–	–	0.30	0.14	0.25	0.23
Variance, R^2	0.0003	–	0.07	–	0.05	–
Log-likelihood	–112.69	–	–112.02	–	–112.13	–
Lagrange multiplier statistic	–	–	1.06	0.30	1.02	0.31
Akaike information criterion	229.39	–	228.04	–	230.25	–

out effectively to the socioeconomically disadvantaged and underserved by careful microplanning at the district level involving intersectoral coordination, political commitment, social mobilisation and constant monitoring and supervision. Such bottom-up approaches will be crucial to address the unmet gaps in VAS coverage unravelled in a district-wise manner by this study.

The VAS coverage values further exhibited spatially significant patterns (spatial autocorrelation). This included both ‘low–low’ and ‘high–high’ clusters. The ‘low–low’ locations were observed in contiguous districts from Nagaland and Manipur in NER, and also in contiguous districts from Uttar Pradesh, Uttarakhand and Rajasthan in northern India. The ‘high–high’ locations were primarily seen in some districts from southern India. Finding such ‘interesting locations’ is an integral aspect of exploratory spatial data analysis. In addition to knowledge discovery, they stimulate new hypothesis and seek to find targeted solutions.^{27 32–34} For example, the low–low cluster indicates the possible presence of barriers that had systemically hampered VAS coverage in the affected districts. Identification of such root causes and their redressal would enhance the programme coverage. Likewise, the high–high cluster of districts may prompt the search for certain ‘best practices’ that had a systemic contribution in facilitating VAS, and which may be emulated to improve the coverage in other districts.

Interestingly however, the spatial distribution of VAD (identified by biochemical measurements of serum retinol) prevalence among under-five children did not vary as a function of VAS coverage rates in the states of India. This was possibly because high-dose VAS has only small and transient impact on serum retinol concentrations,^{47–49} and therefore may be inadequate to mitigate the VAD burden defined on the basis of serum retinol alone. Although regarded as an important public health nutritional intervention, the usefulness of the dated vitamin A policy (that encourages routine practice of universal VAS) is being increasingly questioned,^{19 47–50} with calls for more nuanced and sustainable alternatives. It is true that the coverage of VAS, even in the recent past, was found to influence the prevalence of VAD-related health problems like childhood blindness in some affected nations.^{51 52} But there are also concerns (in India and elsewhere) that the routine practice of administering massive vitamin A doses indiscriminately has outlived its intended usefulness and that its further

continuation may actually put children at risk of developing vitamin A toxicity.^{19 47–50 53–55} It is more so with the concurrent scaling up of various food-based initiatives (eg, fortification of edible oil and milk with retinol).^{19 47 50 54–56} Though detrimental (especially in the long run), the immediate manifestations of vitamin A excess/toxicity are often inconspicuous and non-specific,^{57–59} and therefore may be missed. In this context, it may be worth monitoring for any evidence of vitamin A excess/toxicity in the high VAS coverage areas. Similarly, the magnitude of VAD and the attendant risks to child health and survival should be closely investigated, particularly in the locations with poor VAS coverage. In fact, sporadic studies in the past had documented laboratory and/or clinical evidence of sizeable VAD burden in some of these locations.^{18 60} Hence, careful surveillance of VAD and vitamin A toxicity in the community is needed to inform and facilitate strategies for focusing vitamin A interventions for the vulnerable and the ones in need.^{47 49 50} Simultaneously, to obtain a comprehensive picture, it is also desirable to survey the intake of vitamin A (accounting for natural as well as fortified food items) in the population. These data would be most informative if collected at a granular level, for example, by districts.

Despite these insightful results and their implications, there were limitations that warrant a cautious appreciation of certain aspects in the study findings. For example, although it was desirable to substantiate the observed lack of spatial association between VAS coverage and VAD prevalence at the district-level (since state-level analyses alone tend to mask the interdistrict and intrastate differences in VAS coverage), the unavailability of district-wise VAD estimates precluded that evaluation. The analysis was also constrained by the cross-sectional nature of the data from the two surveys which prevented the drawing of causal inferences. Lastly, the clusters identified by LISA maps may have the potential to be slightly unintuitive for specific values of alpha (as described above). Therefore, these maps should be carefully interpreted taking into account both the default and sensitivity analyses and the absolute values of VAS coverage across the country.

CONCLUSION

This report provides a detailed overview about geographical heterogeneities and gaps in the outreach of VAS among

under-five Indian children with implications for targeted coverage. The coverage of VAS was described in 640 districts of India encompassing all the 29 states and 7 UTs. The spatial distribution of VAS coverage in individual states/UTs was not associated with the corresponding prevalence of VAD defined on the basis of serum retinol measurements. Nationally, nearly two out of every five Indian children in the eligible age range were not supplemented with vitamin A during the reporting period. Subnationally, the coverage values showed considerable geographical variations with spatial autocorrelation. While most of the low VAS coverage areas were located in Manipur, Nagaland, Arunachal Pradesh, Uttar Pradesh, Uttarakhand and Rajasthan; the high coverage areas were mostly located in Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Maharashtra, Goa, Gujarat, Sikkim, Punjab and Haryana. It calls for closely monitoring the impact of the VAS coverage on the spatial distribution of vitamin A status and the associated health effects in the population, so that appropriate interventions may be microplanned and channelised for the people in need.

Acknowledgements The author fondly remembers the constant motivation and guidance by Professor Siddhartha Majumder, ex-Head, Department of Experimental Medicine, PGIMER Chandigarh and ex-Chairman, Scientific Advisory Committee, ICMR-RMRCNE Dibrugarh; and mourns his recent demise after prolonged illness. The author is grateful for the exposure received on GIS and geospatial analysis through capacity building programmes organised by the Indian Institute of Remote Sensing, ISRO, Dehradun. The author also thanks Dr Kanwar Narain, Director, ICMR-RMRCNE Dibrugarh for the encouragement and administrative support while carrying out this research. Further, the author is thankful to the anonymous reviewers for their insightful feedback and constructive criticism.

Contributors KB conceptualised the study, performed data analysis and interpretation, wrote the first draft of the manuscript and critically revised it. KB accepts full responsibility as guarantor for the finished work and the conduct of the study, had access to the data, and controlled the decision to publish.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Map disclaimer The inclusion of any map (including the depiction of any boundaries therein), or of any geographical or locational reference, does not imply the expression of any opinion whatsoever on the part of BMJ concerning the legal status of any country, territory, jurisdiction or area or of its authorities. Any such expression remains solely that of the relevant source and is not endorsed by BMJ. Maps are provided without any warranty of any kind, either express or implied.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. The data used in this study can be accessed at the following links: <https://dhsprogram.com/methodology/survey/survey-display-355.cfm> and <http://rchiips.org/nfhs/>

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